(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 426 488 B1

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
23.04.1997 Bulletin 1997/17

(51) Int Cl.[6]: **C12N 9/02**, C08G 85/00

(21) Application number: **90312027.7**

(22) Date of filing: **02.11.1990**

(54) **Production of modified superoxide dismutase**

Verfahren zur Herstellung modifizierter Superoxid-Dismutase

Procédé de préparation de superoxyde-dismutase modifiée

(84) Designated Contracting States:
CH DE ES FR GB IT LI

(30) Priority: **02.11.1989 JP 286798/89**

(43) Date of publication of application:
08.05.1991 Bulletin 1991/19

(73) Proprietor: **NIHON CHEMICAL RESEARCH KABUSHIKI KAISHA also known as JCR PHARMACEUTICALS CO., LTD**
Kobe Hyogo 658 (JP)

(72) Inventors:
- **Nakano, Yoshiyuki Neohaitsu Sannomiya 604**
  Kobe Hyogo 651 (JP)
- **Hiratani, Hajime**
  Osaka 599-02 (JP)
- **Kato, Kazuo**
  Kita-ku Kobe Hyogo 651-11 (JP)

(74) Representative: **Smart, Peter John et al**
W.H. BECK, GREENER & CO
7 Stone Buildings
Lincoln's Inn
London WC2A 3SZ (GB)

(56) References cited:
EP-A- 0 200 467

- **ANALYTICAL BIOCHEMISTRY, vol. 131, no. 1, 1983; C.O. BEAUCHAMP et al., pp. 25-33**

EP 0 426 488 B1

Description

This invention relates to processes for producing modified superoxide dismutases. Modified superoxide dismutases are utilizable as pharmaceuticals, such as treatment agents of ischemic diseases or radiation hazards, and antitumor agents; In cosmetics intended for use in the prevention of oxygen injuries occurring on the skin; and for other purposes.

Superoxide dismutase (SOD) occurs naturally in the biosphere or living world extensively and is known as an enzyme capable of eliminating superoxide anion radicals (hereinafter referred to briefly as "radicals") which are metabolites of oxygen. SOD is found out in all and every living beings or organisms that require oxygen for growth, such as animals, plants and microorganisms.

It has been discovered and confirmed in man that SOD exists in three different types; SOD containing copper and zinc, SOD having manganese and extracellular SOD being present outside cells, among which the type containing copper and zinc is widely known to the general public. Reports have been made that such different types of SOD are effective for rheumatism and arthritis deformans, and in expectation of preventing injuries by ischemia- recirculation, for example, clinical trials are currently under way but in most cases through administration of SOD in the unmodified state. In the light of the fact that such types of SOD show a half-life in the blood as short as some minutes after administration, it cannot be said that SOD is allowed to produce its own effects to the maximal extent; in other words, the efficacy testing has been conducted only on a limited scope.

This invention is concerend with a process which can permit modified superoxide dismutases with a high degree of purity having a markedly elongated blood half-life and consequently finding a wide range of clinical application as a drug substance to be produced on a commercial scale in simplified manners and in increased yields. Heretofore,a great variety of chemical modifications have been performed in order to provide SOD with a prolonged half-life in the blood. For example, modification of SOD was made with high-molecular-weight dextran (W. F. Petrone et al., Proc. Natl. Acad. Sci. U.S.A., 77, 1159 (1980)), polyethylene glycols (The Japanese Unexamined Patent Publication Nos. 249,388/61, 115,280/62 and 245,671/63, and a report by Charles Obeauchamp et al. (Analytiucal Biochemistry, 131, 25-33 (1983)) or inulin (The Japanese Unexamined Patent Publication No. 32,826/58). Nevertheless, the said modified SODs as well as the above-mentioned processes for the production of such SODs suffer from various disadvantages to be described below, resulting in failure to solve the problems satisfactorily.

The above-described SOD derivatives have all been developed for the purpose of preventing oxidative tissue injuries in the living body through intravenous and intramuscular administration. Except as stated in the above report by Charles O. Beauchamp et al., all of such derivatives are the high-molecular-weight modified SODs that are produced by use of activated modifying agents having two functional groups derivatives with the result that two molecuiles of SOD are introduced, and consequently, they are provided with an extremley extended half-life in the blood; they present the disadvantage that they remain in the living body for a too much long period of time, although they offer the advantage of having a longer blood half-life than unmodified SOD. Beauchamp et al., in their report mentioned previously, described that they succeeded in making improvements on such disadvantage through the activation of N,N'-carbonyldiimidazole (CDI) to thereby supply polyethylene glycol (PEG) with only one functional group. However, the method suffers from the defects that the treatment batch size is too small to conduct the commercial production of modified SOD, particularly the large-volume production of the same for pharmaceutical uses, and that the treatment requires a prolonged length of time.

Taking into consideration the above situation, this invention has been devised after intensive investigation into the large-volume production of SOD modified with polyethylene glycol (hereinafter referred to briefly as "PEG-SOD") or SOD modified with polyoxyethylene glycol·polyoxypropylene glycol·polyoxyethylene glycol (hereinafter referred to briefly as "PEG-PPG-SOD") to thus utilize them in the application fields as pharmaceuticals.

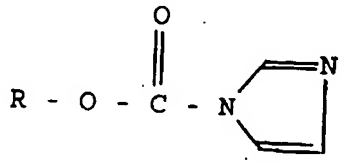
The present inventors, in the course of research activities carried out on the application of proteins to pharmaceuticals, found that prolongation of blood half-lives of proteins can permit the application scope of proteins to be maximized, and have already filed an application for patent covering the efficacy-sustainable type of proteins as per Japanese Unexamined Patent publication No. 59029/59. Unmodified superoxide dismutase (SOD), that is usable in this invention, has in recent years been attracting enhanced attention as a pharmaceutical, and vigorous clinical studies are under progress with SOD.

Taking notice of the facts that unmodified SOD shows a blood half-life as short as some minutes in rats and that SOD elicits drug efficacy at by far larger doses than generally considered for the enzymatic proteins for medicinal uses, however, the present inventors have conducted repeatedly intensive research on a simplified method, as a means of elimianting such defects, of producing high-purity modified dismutase in improved yields that can realize the large-volume treatment. As described in the above, Beauchamp et al. reported the SOD modified with PEG activated by CDI but their production method encounters difficulties in large-scale production in terms of facilities.

The present invention, being intended to overcome such difficulties, is concerned with a process of producing modified superoxide dismutaes represented by the formula:

$$R - O - C - NH - \underline{SOD} \qquad (II)$$

(wherein R is as defined below; SOD is a residue of superoxide dismutase), characterized in that said process comprises reacting a water-soluble polyoxyalkylene polymer having a molecular weight of 2,000 to 10,000 with carbonyldiimidazole to produce a polymeric carbonylimidazole represented by the formula:



wherein R is a residue of the polyoxyalkylene polymer, and reacting the polymeric carbonylimidazole with a superoxide dismutase in the presence of a buffer to form the modified superoxide dismutase characterised in that the (molar) concentration ratio of said polymer to said carbonyldiimidazole is from 1:1 to 1:3, the reaction with the carbonyldiimidazole is discontinued through addition of a buffer without bringing about an increase in pH to produce the polymeric carbonylimidazole and the polymeric carbonylimidazole is reacted with the dismutase in the presence of a buffer having a pH of 9.0 to 11.0 and a concentration of 0.1 to 0.5 M at a temperature of 30 to 70°C for a sufficient length of time to form the modified superoxide dismutase.

Preferably said temperature is in the range of 45 to 60°C. Preferably said concentration is in the range of 0.2 to 0.4 M.

The polymeric carbonyldiimidazole derivative of the formula (I) can be obtained by reacting said water-soluble polymer having a molecular weight of 2,000 to 10,000 with said carbonyldiimdiazole (CDI) in an inert solvent such as dioxane.

As the water-soluble polyoxyalkylene polymer, there may be mentioned, for example, polyalkylene glycols having a molecular weight of about 2,000 to 10,000, such as polyethylene glycols, mono-lower-alkoxypolyethylene glycols and mono-lower-alkoxypolyethylene polypropylene polyethylene glycols. The above-mentioned lower alkoxies usually are C_1 to C_4 alkoxy groups. Preferred examples of the water-soluble polymer include monomethoxypolyethylene glycols having an average molecular weight of 3,500 and monomethoxypolyethylene polypropylene polyethylene glycols having the same molecular weight.

In order to increase and also maintain at the increased, fixed level the ratio of activation of the water-soluble polymer with CDI, the water-soluble polymer desirably is added into a reaction solvent in such a quantity as its initial concentration may range from 0.15 to 0.35 M, preferably from 0.25 to 0.3 M, while the initial concentration ratio of the polymer to CDI is 1:1 to 3, preferably 1:1.5 to 2.5.

Choice of the above concentrations can lead to reduced volume of the reaction solution.

Also, the ratio of activation of the polymer can be maintained at a fixed level through addition of a weekly acid buffer having a pH range of 6 to 6.5 to the reaction mixture to thereby allow the reaction to discontinue without increasing its pH.

After conclusion of the reaction, the derivative of the formula (I) can be separated from the reaction mixture by use of such separatory means as dialysis and lyophilization.

Table 1 shows the comparison of an example with this invention and the method of Beauchamp et al. The decided differences between the process of the present inventors and the one of Beauchamp et al lie in the concentration of the modifying agent as well as the discontinuation of the reaction through addition of a buffer without bringing about an increase in pH value, as employed and effected individually in the production of the activated modifying agent being shown in (A) of Table 1. In the course of intensive research on the improvement of reaction conditions, it has been found that the improvement of the said two conditions are essential for the stable large-scale production of the activated modifying agent; namely, the optimally increased concentration of the modifying agent facilitates the activation in large quantities. Although Beauchamp et al conducted investigation at 1:10 of the concentration ratio of the modifying agent to the activating agent CDI, the present inventors found out that when the said concentration ratio is maintained at 1:1 to 1:3, preferably 1:1.5 to 1:2.5, the modification can best be performed reliably. Also, the increased concentration of the modifying agent can permit the volume of reaction solution to be reduced. The optimal range of the concentration can be selected from 0.15 to 0.35 M, preferably from 0.25 to 0.3 M. This enables the utilisation of the equipment capable of concentrating furthermore and reaction solution after conclusion of the reaction, resulting in simplified subsequent treatment steps. Table 1 (B), in which the modification of SOD with activated PEG or PEG-PPG is described, can

elucidate more clearly the characteristic features of this invention. According to this invention, it has been proven that the increased concentration of the buffer makes it possible to minimize a change in pH due to a varying amount of the protein and furthermore that a rise in pH can accelerate the reaction rate. The buffer desirably shows a pH of 9 to 10 and a concentration of 0.1 to 0.5 M, preferably 0.2 to 0.4 M. The composition of the buffer is not particularly limited, buffers being suitable if they have buffering capacity over the pH range of this invention and can be easily prepared. Sodium carbonate buffer is preferable, because it is often used as an additive for pharmaceutical preparations and is considered highly safe. The present inventors carried out extensive investigation into a large-scale production process in which the modification reaction of SOD with activated PEG or PEG-PPG can be conducted faster, and as a result, found that reaction at temperatures of 30 to 70°C, preferably 45 to 60°C, can lead to completion of the modification within an extremely shortened period of time. For other proteins not necessarily being heat-stable, heretofore, it has been con-sidered undesirable to allow the modification reaction to proceed at the above-described high temperatures, but this invention has unexpectedly brought excellent results. Furthermore, the present invention found that the modification reaction can be carried out with the concentrations of both activated PEG or PEG-PPG and SOD being increased, thus making the commercial, large-scale production practically feasible. In view of the fact that this invention is originally intended for the production of PEG or PEG-PPG modified SOD, it is not desirable to produce the modified SOD contaminated with unmodified SOD or activating agent. As a counter-measure against the former, therefore, the present inventors found

TABLE 1:

Comparison of this invention with the method of Beauchamp et al		
(A) Activation of PEG with CDI		
	This invention	Beauchamp et al
Solvent	Dioxane	Dioxane
Modifying agent	PEG-PPG	PEG
Concn. of modifying agent	300 mM	50 mM
Concn. of activating agent (CDI)	600 mM	500 mM
Temperature	30°C	37°C
Reaction time	2 hrs.	2 hrs.
Concentration treatment (evaporator)	Employed	Not employed
Discontinuation of reaction	Addition of buffer	
Dialysis (outer soln.)	Water	Water
Lyophilization	Employed	Employed
Ratio of activation	> 9	6 to 8
(B) Activation of SOD with activated modifying agent		
	This invention	Beauchamp et al
Buffer	100 to 500 mM sodium borate (pH 9.5) or sodium carbonate (pH 9.5)	10 mM sodium borate (pH 8.5)
Concn. of activated modifying agent	5.0 to 100 mM	180 mM
Concn. of SOD	1 to 2 mM	0.05 mM
Reaction temp.	40 to 60°C	4°C
Reaction time	0.5 to 1 hr.	48 to 98 hrs.
No. of modification	Once or twice	Once
Purification	DEAE chromato.	Unknown
Ratio of modification	17 to 20%	5 to 10%
Blood half-life	14 hrs.	9 hrs.
Retention of SOD activity	92 to 98%	95%

that twice repeated modification reactions can result in complete disappearance of unmodified SOD, although even one modification reaction yields modified SOD with less than 8% in content of unmodified SOD being satisfactorily usable in the pharmaceutical field. Furthermore, it was discovered that anion exchange column chromatography is an effective means for the entire elimination of contamination with unreacted activating agent. Since the unmodified activating agent and the modified SOD have individually different molecular weights of 32,000 and 130,000, it usually is a common practice to employ molecular sieve column chromatography, but the present inventors found that anion

exchange column chromatography, being more efficient, is best suited for the said purpose. Use can be made of any anion exchangers that possess DEAE groups, but preferably DEAE-Sepharose CL-6B may be usable. It was found that the SOD being modified in this manner with activated PEG or PEG-PPG shows a ratio of modification as constant as 17 to 20% and that such modified SOD can be produced more efficiently than in the case of the method of Beauchamp et al. When a chemical compound is intended for use as a pharmaceutical, considered to be the most desirable is the production process being capable of securing constancy of results, and in the light of the characteristics as described above, the process according to this invention can be said to fully meet such requirement.

SOD that is usable in this invention is not particularly limited in terms of its origin or source, but desirably SOD contains copper and zinc.

Below described are examples of the invention and the results of experiments conducted on the products of said examples. Analytical methods employed are described first.

Assay of SOD activity

Employed was the procedure of McCord and Fridovich (J.C.B., 244, 6049-6055(1969)), according to which procedure in the superoxide generating system with xanthine-xanthine oxidase where cytochrome C and unmodified SOD or modified SOD were allowed to co-exist, the amount of either of such unmodified or modified SOD needed to lower the rate of cytochrome C reduction was determined as an index for assaying the enzymatic activity. The retention (%) of the enzymatic activity of modified SOD was expressed in terms of a proportion on the basis of the enzymatic activity (taken as 100%) of unmodified SOD as assayed against the superoxide generated in the xanthine-xanthine oxidase system.

Determination of ratio of modification

To a 0.6 M boric acid sodium hydroxide buffer having a pH of 9.5 were added 0.1 ml of unmodified SOD, 0.1 ml of 0.2 N sodium hydroxide reagent solution and 0.1 ml of sodium 2, 4.6-trinitrobenzenesulfonate (7.2 mg/ml of water, referred to as "TNBS"), and the reaction was allowed to proceed over a water bath for 3 hours at 25°C. The reaction solution was subjected to measurement of absorbance at a wavelength of 367 nm. The amount of protein is plotted as abscissa and the absorbance as ordinate to prepare a calibration curve (an inclination:A) for TNBS coloration of unmodified SOD. The same procedure was repeated with modified SOD to prepare a calibration curve (an inclination: B) for TNBS coloration of modified SOD. The ration (%) of modification was calculated by the equation of [(A-B)/A] x 100.

Determination of molecular weight

Determination of molecular weights was carried out by means of high-performance liquid chromatography (HPLC) with use of TSK G 3000 SW (produced by Toso K.K. of Japan); chromatography was conducted while utilising as a solvent 0.1 M sodium phosphate buffer of pH 7.0 containing 0.3 M sodium chloride flowing at a rate of 1.0 ml/min.

Analysis by electrophoresis

Electrophoresis was performed with the use of First System (supplied by Pharmacia Co.), 8 to 25% polyacrylamide concentration-gradient gel, and the protein was stained with Coomassie Brilliant Blue R-250.

Quantitative determination of proteins

According to the biuret method of A.G. Cornall et al (J.B.C., 177, 751(1949)), the protein was reacted with divalent copper under alkaline conditions, and the resulting red-purple reaction solution was subjected to measurement of absorbance at a wavelength of 540 nm. The protein was determined quantitatively through calculation from a calibration curve prepared with bovine serum albumin used as a standard.

Experiment Example 1

- Half-life in the blood -

House rabbits, being used as experimental animals, were given intravenously SOD modified with PEG-PPG (a molecular weight of 3,500) and unmodified SOD, as replaced with or dissolved in isotonic saline, at a dose of 38,000 units per 2.5 kg body weight, respectively, followed by time-course determination of the serum SOD levels. The results (obtained with two house rabbits) are shown in Fig. 1, which indicates that the modified SOD, showing a lowered rate

of blood clearance as compared with unmodified SOD, extended the length of the time of SOD activity development in the blood. However, this does not necessarily mean that the modified SOD resides in the blood forever; as its blood level dropped 24 hours later to about the one prior to administration, the modified SOD was thought to be cleared from the blood and to be then excreted. This fact is considered to be of utmost importance, since it demonstrates that the process was able to produce the modified SOD that was provided with a suitably extended, but not excessively prolonged, SOD-activity lifetime as compared with unmodified SOD.

Experiment Example 2

- Antigenicity -

In accordance with the procedure as described in Journal of Immunological Methods, 14, 381(1977), the modified SOD was tested to find out whether or not it would develop any novel type of antigenicity. Unmodified SOD or modified SOD (ca. 30 μg each) was emulsified with Freund Complete Adjuvant (FCA) and was given A/J mice intraperitoneally, followed by additional administration on Day 14 and Day 28 for immunization. Blood samples were drawn from the mice through the ocular vein in the time course manner at the interval of one week starting with the day of initiation of injection to separate the sera, and the sera after being diluted in advance were given rats through intradermal injection (0.1 ml), followed by Intravenous injection of 2 ml of a mixed solution of unmodified SOD (0.5 mg) and Evans blue dye (20 mg) 4 hours later to thus conduct an assessement test for the production of antibody through the passive cutaneous anaphylaxis reaction (PCA reaction) wherein the judgement was made on the basis of vascular permeability of the dye. The results are shown in Table 2, where the figures designate the maximum dilution multiples of the sera at which the PCA reaction turned positive; namely, their larger numerical values mean stronger antigenicity.

Table 2:

Antigenicity tests						
	No. of animals	PCA - Titer				
		Day 7	Day 14	Day 21	Day 28	Day 35
Unmodified SOD	10	8	32	128	256	256
Modified SOD	10	0	0	0	0	0

Teh results as shown in Table 2 indicate that unmodified SOD, becasue of its human source, elicited antigenicity, whereas the modified SOD as produced in accordance with this invention did not produce antigenicity in any animal; this experiment, where SOD of human source was used in the animals of a different species, demonstrated that the modification caused a reduction in the proper antigenicity of human SOD.

Experiment Example 3

Shown in Table 3 are the comparisons in specific activity of unmodified SOD with different modified SOD as produced in the examples.

Table 3:

Sample	U/mg protein
Unmodified SOD	3,800
Modified SODs:	
Example 1	3,800

Example 2	3,800
Example 3	4,100
Example 4	4,100
Example 5	3,800

All modified SODs were found not to bring about any reduction in specific activity, which is in sharp contrast to unmodified SOD. This means that the production process according to this invention was able to retain the superoxide anion radical eliminating effect of SOD as it was in-the natural state, and the finding, coupled with the results of Experiment Example 1, demonstrates definitely that modified SOD having a half-life in the living body alone prolonged was able to be produced.

Example 1

(1) Production of carbonyldiimdiazole-monomethoxy polymer:

Into 100 ml of dioxane were 100 g of monomethoxypolyethylene glycol polypropylene glycol polyethylene glycol (an average molecular weight of 3,500, produced by Toho Chemical Co. of Japan. EO : PO : EO = 1500 : 500 : 1500. hereinafter referred to as "OMe-PEG-PPG") and 10 g of carbonyldiimidazole (hereinafter referred to as "CDI"), and the mixture was stirred for 2 hours at 30°C to produce a solution and simultaneously to allow the reaction to proceed, resulting in a reaction solution containing a CDI derviative of OMe-PEG-PPG (hereinafter referred to as "CDI-PEG-PPG"). In order to remove the dioxane from the rection solution, the reaction solution was concentrated under reduced pressure over a water bath at a temperature of lower than 30°C to give about 110 ml of a highly viscous concentrate, to which 0.5 M sodium phosphate buffer (pH 6.5) was then added to make up to 200 ml. The diluted solution was subjected to dialysis treatment (the outer solution: water) to give 1,000 ml of the sample solution, followed by lyophilization to produce CDI-PEG-PPG in the form of dried powder, which was stored at -30°C. Yield of 98 %.

(2) Production of SOD modified with PEG-PPG:

To a reaction vessel containing 100 ml of 0.3 M sodium carbonate buffer (pH 9.5) was added 5 g of of lyophylized SOD in such a manner as its final concentration might be at 50 mg/ml, and stirring was performed while immersing the reaction vessel into a contant-temperature bath controlled at a temperature of 50°C. Then, 17.5 g of CDI-PEG-PPG as produced under the previous section (1) was added to the mixture, followed by further addition of the same amount of CDI-PEG-PPG. After the reaction was continued for about 30 min, the reaction solution was subjected to dialysis (the outer solution: water) to give a solution containing crude PEG-PPG-SOD.

(3) Purification of a solution of crude PEG-PPG-SOD:

The solution of crude PEG-PPG-SOD, as produced under the section (2), was poured for adsorption into a column packed with DEAE-Sepharose CL-6B (produced by Pharmacia Co.) which had been equilibrated through thorough washing with a sufficient volume of water, and the column was washed with a volume of water five times the volume of the column to remove unreacted CDI-PEG-PPG. The adsorbed PEG-PPG-SOD was eluted with 0.3 M sodium carbonate-hydrochloric acid buffer (pH 9.5), and the eluate was concentrated through ultrafiltration.

(4) Reaction of SOD re-modified with PEG-PPG:

Becasue the PEG-PPG-SOD as produced under the section (3) was found to contain unreacted SOD, the concentrate obtained through ultrafiltration under the section (3) was adjusted to a concentration of 50 ± 5 mg/ml and subjected to the same procedure as performed under the section (2) to give a crude solution of SOD completely modified with PEG-PPG, which was then chromatographed on a column of DEAE-Sepharose by the same procedure as described under the section (3). The elution was performed with 25 mM sodium phosphate buffer (pH 7.0) containing 0.9 % sodium chloride, and the eluate was concentrated through ultrafiltration and sterile-filtered to give a pure PEG-PPG-SOD solution. Yield of 4.8 g or 96 %. The product was found to be a pure and single compound as evidenced by TSK G 3000SW gel permeation and electrophoresis analyses (see Fig. 2).

Example 2

(1) Production of carbonyldiimidazole-monomethoxy polymer:

To 500 ml of dioxane were added 500 g of OMe-PEG-PPG as described in Example 1 and 50 g of CDI, and the mixture was stirred for 2 hours at 30°C to produce a solution and simultaneously to allow the reaction to proceed, thereby resulting in a reaction solution containing a CDI derivative of PEG-PPG (CDI-PEG-PPG). In order to remove the dioxane from the reaction solution, the reaction solution was concentrated under reduced pressure over a water bath at a temperature of lower than 30°C to produce about 600 ml of a highly viscous concentrate, followed by addition of 0.5 M sodium phosphate buffer (pH 6.5) to dilute to 1000 ml. Furthermore, the diluted solution was subjected to dialysis treatment (the outer solution: water) to give 5000 ml of a sample solution, followed by lyophylization to produce CDI-PEG-PPG in the form of dried powder. The product was stored at -30°C. Yield of 99 %.

(2) Production of superoxide dismutase modified with PEG-PPG:

Into a reaction vessel containing 500 ml of 0.3 M sodium carbonate buffer (pH 9.5) was added 30 g of SOD in such a manner as its final concentration might be at 60 mg/ml, and stirring was performed while immersing the reaction vessel in a contant-temperature bath controlled at a temperature of 55°C. 87.5 g of CDI-PEG-PPG as produced under the section (1) was added to the mixture, followed by further addition of the same amount of CDI-PEG-PPG 30 minutes later. After the reaction was continued for about 30 minutes, the reaction solution was subjected to dialysis treatment (the outer solution: water) to give a crude PEG-PPG-SOD solution.

(3) Purification of the crude PEG-PPG-SOD solution:

The crude PEG-PPG-SOD solution as obtained under the section (2) was poured for adsorption into a column packed with DEAE-Sepharose CL-6B (produced by Pharmacia Co.) which had been equilibrated through thorough washing with sufficient volume of water, and the column was washed with a volume of water five times the volume of the column to remove unreacted CDT-PEG-PPG. The adsorbed PEG-PPG-SOD was eluted with 0.3 M sodium carbonate buffer (pH 9.5), and the eluate was concentrated through ultrafiltration.

(4) Reaction of SOD re-modified with PEG-PPG:

Because the SOD modified with PEG-PPG as produced under the section (3) was found to contain 1.5 % of unreacted SOD, the concentrate obtained through ultrafiltration under the section (3) was adjusted to a concentration of 50 ± 5 mg/ml and subjected to the same procedure as described in the section (2) to give a crude solution of SOD completely modified with PEG-PPG. The crude PEG-PPG-SOD solution was chromatographed on a column of DEAE-Sepharose in the same manner as described under the section (3), followed by elution with 2.5 mM sodium phosphate buffer (pH 7.0) containing 0.9 % of sodium chloride, and the eluate was comcentrated through ultrafiltration and sterile filtered to give a pure PEG-PPG-SOD solution. Yield of 29 g or 97 %. The product was found to be a pure and single compound as evidence by electrophoresis analysis.

Example 3

(1) Production of carbonyldiimidazole-monomethoxy polymer:

Into 100 ml fo dioxane were added 100 g of monomethoxypolyoxyethylene glycol (an average molecular weight of 3,500, produced by Toho Chemical Co. hereinafter referred to as "OMe-PEG") and 10 g of CDI, and stirring was performed to produce a solution and simultaneously to allow the reaction to proceed, resulting in a reaction solution containing a CDI derivative of PEG (CDI-PEG). In order to remove the dioxane from the reaction solution, the reaction solution was concentrated under reduced pressure over a water bath at a temperature of lower than 30°C to give about 105 ml of a highly viscous concentrate, to which 0.5 M sodium phosphate buffer (pH 6.5) was added to make up to 180ml. Furthermore, the diluted solution was subjected to dialysis treatment (the outer solution: water) to give 950 ml of a sample solution, followed by lyophilization to produce CDI-PEG in the form of dried powder. The product was stored at -30°C. Yield of 98 %.

(2) Production of superoxide dismutase modified with PEG:

Into a reaction vessel containing 100 ml of 0.3 M sodium borate buffer (pH 9.5) was added 5 g of lyophilized SOD

in such a manner as its final concentration might be at 50 mg/ml, and stirring was performed while immersing the reaction vessel in a contant-temperature bath controlled at a temperature of 50°C. 17.5 g of CDI-PEG as produced under the section (1) was added to the mixture, followed by further addition of the same amount of CDI-PEG 30 minutes later. After the reaction was continued for about 30 minutes, the reaction solution was subjected to dialysis treatment (the outer solution: water) to give a crude PEG-SOD solution.

(3) Purification of crude PEG-SOD solution:

The crude PEG-SOD solution as obtained under the section (2) was poured for adsorption into a column packed with DEAE-Toyo Pearl (produced by Toso Inc. of Japan) which had been equilibrated through thorough washing with sufficient volume of water, and the column was washed with a volume of water five times the volume of the column to remove unreacted CDIPEG. The adsorbed PEG-SOD was eluted with 0.3 M sodium carbonate buffer (pH 9.5), and the eluate was concentrated through ultrafiltration.

(4) Reaction of SOD re-modified with PEG:

Because the PEG-SOD as produced under the section (3) was found to contain about 7 % of unreacted SOD, the concentrate obtained through ultrafiltration under the section (3) was adjusted to a concentration of 50 ± 5 mg/ml and subjected to same procedure as described under the section (2) to give a crude solution of SOD completely modified with PEG. The crude PEG-SOD solution was further chromatographed on a column of DEAE-Toyo Pearl in the same manner as described in the section (3), followed by elution with 25 mM sodium phosphate buffer (pH 7.0) containing 0.9 % of sodium chloride., and the eluate was concentrated through ultrafiltration and sterile filtered to give a pure PEG-SOD solution. Yield of 4.9 g or 98 %. The product was found to be a pure and single compound as evidenced by gel permeation on TSKG 3000 SW and electrophoresis.

Example 4

(1) Production of carbonyldiimidazole-monomethoxy polymer:

Into 200 ml of dioxane were added 200 g of PEG-PPG (an average molecular weight of 7,000) as used in Example 1 and 20 g of CDI, and stirring was effected for 2 hours at 30°C to produce a solution and simultaneously to allow the reaction to proceed, resulting in a reaction solution containing a CDI derivative of PEG-PPG (CDI-PEG-PPG). In order to remove the dioxane from the reaction solution, the reaction solution was concentrated under reduced pressure over a water bath at a temperature of lower than 30°C to give about 230 ml of a highly viscous concentrate, to which 0.5 M sodium phosphate buffer (pH 6.5) was added to make up to 400 ml. Furthermore, the diluted solution was subjected to dialysis treatment (the outer solution: water) to give 1900 ml of a smple solution, followed by lyophilization to produce CDI-PEG-PPG in the form of dried powder. The product was stored at -30°C. Yield of 94 %.

(2) Production of SOD modified with PEG-PPG:

Into a reaction vessel containing 150 ml of 0.3 M sodium carbonate buffer (pH 9.5) was added 10 g of lyophilized SOD in such a manner as its final concentration might be at 100 mg/ml, and stirring was performed while immersing the reaction vessel in a constant-temperature bath controlled at a temperature of lower than 50°C. Then, 35 g of CDI-PEG-PPG as produced under the section (1) was added to the mixture, followed by further addition of the same amount of CDI-PEG-PPG 30 minutes later. After the reaction was continued for about 30 minutes, the reaction solution was subjected to dialysis treatment (the outer solution: water) to give a crude PEG-PPG-SOD solution.

(3) Purification of the crude PEG-PPG-SOD solution:

The crude PEG-PPG-SOD solution as obtained under the section (2) was poured for adsorption into a column packed with DEAE-Sepharose CL-6B (produced by Pharmacia Co.) which had been equilibrated through thorough washing with sufficient volume of water, and the column was washed with a volume of water five times the volume of the column to remove unreacted CDI-PEG-PPG. The adsorbed PEG-PPG-SOD was eluted with 0.3 M sodium carbonate buffer (pH 9.5), and the eluate was concentrated through ultrafiltration to give about 220 ml of a concentrate, followed by sterile filtration to give 9.85 g of modified SOD solution. Yield of 98.5 %. Gel permeation on TSK G 3000 SW and electrophoresis showed that unreacted SOD was not detected at all.

Example 5

(1) Production of carbonyldiimidazole-monomethoxy polymer:

Into 100 ml of dioxane were added 100 g of PEG-PPG (an average molecualr weight of 1,750) as used in Example 1 and 10 g of CDI, and stirring was performed for 2 hours at 30°C to produce a solution and simultaneously to allow the reaction to proceed, resulting in a reaction solution containing a CDI derivative of PEG-PPG (CDI-PEG-PPG). In order to remove the dioxane from the reaction solution, the reaction solution was concentrated under reduced pressure over a water bath at a temperature of lower than 30°C to give 100 ml of a highly viscous concentrate, to which 0.5 M sodium phosphate buffer (pH 6.5) was added to make up to 200 ml. Furthermore, the diluted solution was subjected to dialysis treatment (the outer solution: water) to give 1000 ml of a sample solution, followed by lyophilization to produce CDI-PEG-PPG in the form of dried powder. The product was stored at -30°C.

(2) Production of SOD modified with PEG-PPG:

Into a reaction vessel containing 100 ml of 0.3 M sodium carbonate buffer (pH 9.3) was added 5 g of lyophilized SOD in such a manner as its final concentration might be at 50 mg/ml, and stirring was effected while immersing the reaction vessle in a constant-temperature bath controlled at a temperature of 50°C. Then, 17 g of CDI-PEG-PPG as produced under the section (1) was added to the mixture, followed by further addition of same amount of CDI-PEG-PPG 30 minutes later. After the reaction was continued for about 30 minutes, the reaction solution was subjected to dialysis tretment (the outer solution: water) to give a crude PEG-PPG-SOD solution.

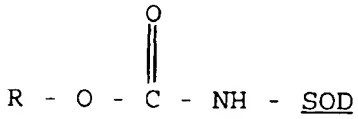
(3) Purification of the crude PEG-PPG-SOD solution:

The crude PEG-PPG-SOD solution as obtained under the section (2) was poured for adsorption into a column packed with DEAE-Sepharose CL-6B (produced by Pharmacia Co.) which had been equilibrated through thorough washing with sufficient volume of water, and the column was washed with a volume of water five times the volume of column to remove unreacted CDI-PEG-PPG. The adsorbed PEG-PPG-SOD was eluted with 0.3 M sodium carbonate buffer (pH 9.5), and the eluate was concentrated through ultrafiltration to give 115 ml of a concentrate, followed by sterile filtration to give 4.89 g of a modified SOD solution. Yield of 97.8 %. Gel permeation on TSK G 3000 SW and electrophoresis showed that unmodified SOD was not detected at all.

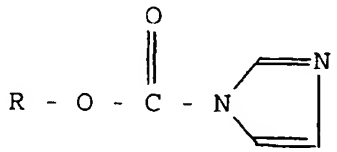
Referring to the drawings, Fig. 1 is a graph showing the time-course changes of the blood levels of modified and unmodified superoxide dismutases in the animal experiment as described in Experiment Example 1, while Fig. 2 is a spectrophotogram of the modified superoxide dismutase as purified through gel permeation in Example 1.

Claims

1. A process for producing a modified superoxide dismutase represented by the formula:



wherein R is as defined below and SOD is a residue of superoxide dismutase, said process comprising reacting a water-soluble polyoxyalkylene polymer having a molecular weight of 2,000 to 10,000 with carbonyldiimidazole to produce a polymeric carbonylimidazole represented by the formula:



wherein R is a residue of the polyoxyalkylene polymer, and reacting the polymeric carbonylimidazole with a su-

peroxide dismutase in the presence of a buffer to form the modified superoxide dismutase characterised in that the (molar) concentration ratio of said polymer to said carbonyldiimidazole is from 1:1 to 1:3 the reaction with the carbonyldiimidazole is discontinued through addition of a buffer without bringing about an increase in pH to produce the polymeric carbonylimidazole and the polymeric carbonylimidazole is reacted with the dismutase in the presence of a buffer having a pH of 9.0 to 11.0 and a concentration of 0.1 to 0.5 M at a temperature of 30 to 70°C for a sufficient length of time to form the modified superoxide dismutase.

2. A process as claimed in Claim 1, wherein the polymeric carbonylimidazole is a carbonylimidazole derivative of a monomethoxypolyethylene glycol having an average molecular weight of 3,500.

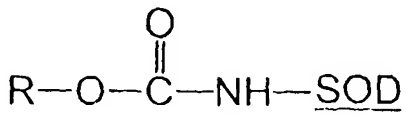
3. A process as claimed in Claim 1, wherein the polymeric carbonylimidazole is a carbonylimidazole derivative of a monomethoxypolyethylene*polypropylene*polyethylene glycol having an average molecular weight of 3,500.

4. A process as claimed in any preceding claim, wherein after conclusion of the reaction, unreacted substances contained in the reaction mixture are removed by means of anion exchange chromatography, followed by recovery of the resulting modified superoxide dismutase with a high degree of purity.

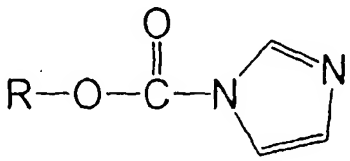
5. A process as claimed in any preceding claim, wherein the concentration of the soluble polyoxyalkylene polymer reacted with carbonyldiimidazole is 0.15 to 0.35 M.

Patentansprüche

1. Verfahren zur Herstellung modifizierter Superoxid-Dismutase der Formel:



worin R wie unten definiert ist und SOD für einen Superoxid-Dismutase-Rest steht, wobei man bei diesem Verfahren ein wasserlösliches Polyoxyalkylenpolymer mit einem Molekulargewicht von 2 000 bis 10 000 mit Carbonyldiimidazol umsetzt, um ein polymeres Carbonylimidazol der Formel



zu erzeugen, worin R für einen Polyoxyalkylenpolmyer-Rest steht, und man das polymere Carbonylimidazol mit einer Superoxid-Dismutase in Gegenwart eines Puffers umsetzt, um die modifizierte Superoxid-Dismutase zu bilden,
dadurch gekennzeichnet, daß
das (molare) Konzentrationsverhältnis von Polymer zu Carbonyldiimidazol 1:1 bis 1:3 beträgt, man die Reaktion mit Carbonyldiimidazol durch Zugabe eines Puffers unterbricht, ohne einen pH-Anstieg zu bewirken, um das polymere Carbonylimidazol zu erzeugen, und man das polymere Carbonylimidazol mit der Dismutase in Gegenwart eines Puffers mit einem pH von 9,0 bis 11,0 und einer Konzentration von 0,1 bis 0,5 M bei einer Temperatur von 30 bis 70°C über einen Zeitraum umsetzt, der ausreicht, um die modifizierte Superoxid-Dismutase zu bilden.

2. Verfahren nach Anspruch 1, wobei das polymere Carbonylimidazol ein Carbonylimidazol-Derivat eines Monomethoxypolyethylenglykols mit einem mittleren Molekulargewicht von 3 500 ist.

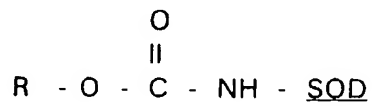
3. Verfahren nach Anspruch 1, wobei das polymere Carbonylimidazol ein Carbonylimidazol-Derivat eines Monomethoxypolyethylen*polypropylen*polyethylenqlykols mit einem mittleren Molekulargewicht von 3 500 ist.

4. Verfahren nach einem der vorhergehenden Ansprüche, wobei nach Reaktionabschluß in der Reaktionsmischung enthaltene, nicht umgesetzte Substanzen mit Hilfe von Anionenaustauschchromatographie entfernt werden und anschließend die resultierende modifizierte Superoxid-Dismutase mit einem hohen Reinheitsgrad zurückgewonnen wird.

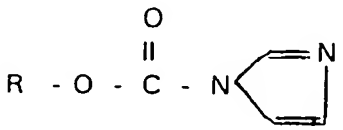
5. Verfahren nach einem der vorhergehenden Ansprüche, wobei die Konzentration des mit Carbonyldiimidazol umgesetzten, löslichen Polyoxyalkylenpolymers 0,15 bis 0,35 M beträgt.

Revendications

1. Procédé de préparation d'une superoxyde-dismutase modifiée représentée par la formule



où R est tel que défini plus bas et SOD est un résidu de superoxyde-dismutase, ce procédé consistant à faire réagir un polymère polyoxyalkylène soluble dans l'eau, ayant un poids moléculaire compris entre 2'000 et 10'000, avec du carbonyldiimidazole pour produire un carbonylimidazole polymère représenté par la formule



où R est un résidu du polymère polyoxyalkylène, et à faire réagir le carbonylimidazole polymère avec une superoxyde-dismutase, en présence d'un tampon, pour former la superoxyde-dismutase modifiée,
caractérisé en ce que

le rapport de la concentration (moléculaire) dudit polymère à celle dudit carbonyldiimidazole est compris entre 1:1 et 1:3;
la réaction avec le carbonyldiimidazole est interrompue par l'addition d'un tampon, sans provoquer une augmentation du pH, pour produire le carbonylimidazole polymère et
le carbonylimidazole polymère est mis en réaction avec la dismutase en présence d'un tampon ayant un pH compris entre 9,0 et 11,0 et une concentration de 0,1 à 0,5 M, à une température de 30 à 70°C, pendant un temps suffisamment long pour former la superoxyde-dismutase modifiée.

2. Procédé selon la revendication 1, caractérisé en ce que le carbonylimidazole polymère est un dérivé carbonylimidazole d'un monométhoxypolyéthylène-glycol ayant un poids moléculaire moyen de 3'500.

3. Procédé selon la revendication 1, caractérisé en ce que le carbonylimidazole polymère est un dérivé carbonylimidazole d'un monométhoxypolyéthylène*polypropylène*polyéthylène-glycol ayant un poids moléculaire moyen de 3'500.

4. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que, lorsque la réaction est terminée, des substances n'ayant pas réagi, contenues dans le mélange de réaction, sont enlevées par chromatographie à échange d'anions, suivie par la récupération de la superoxyde-dismutase modifiée résultante ayant une très grande pureté.

5. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que la concentration du polymère polyoxyalkylène soluble ayant réagi avec le carbonyldiimidazole est de 0,15 à 0,35 M.

FIG. 1

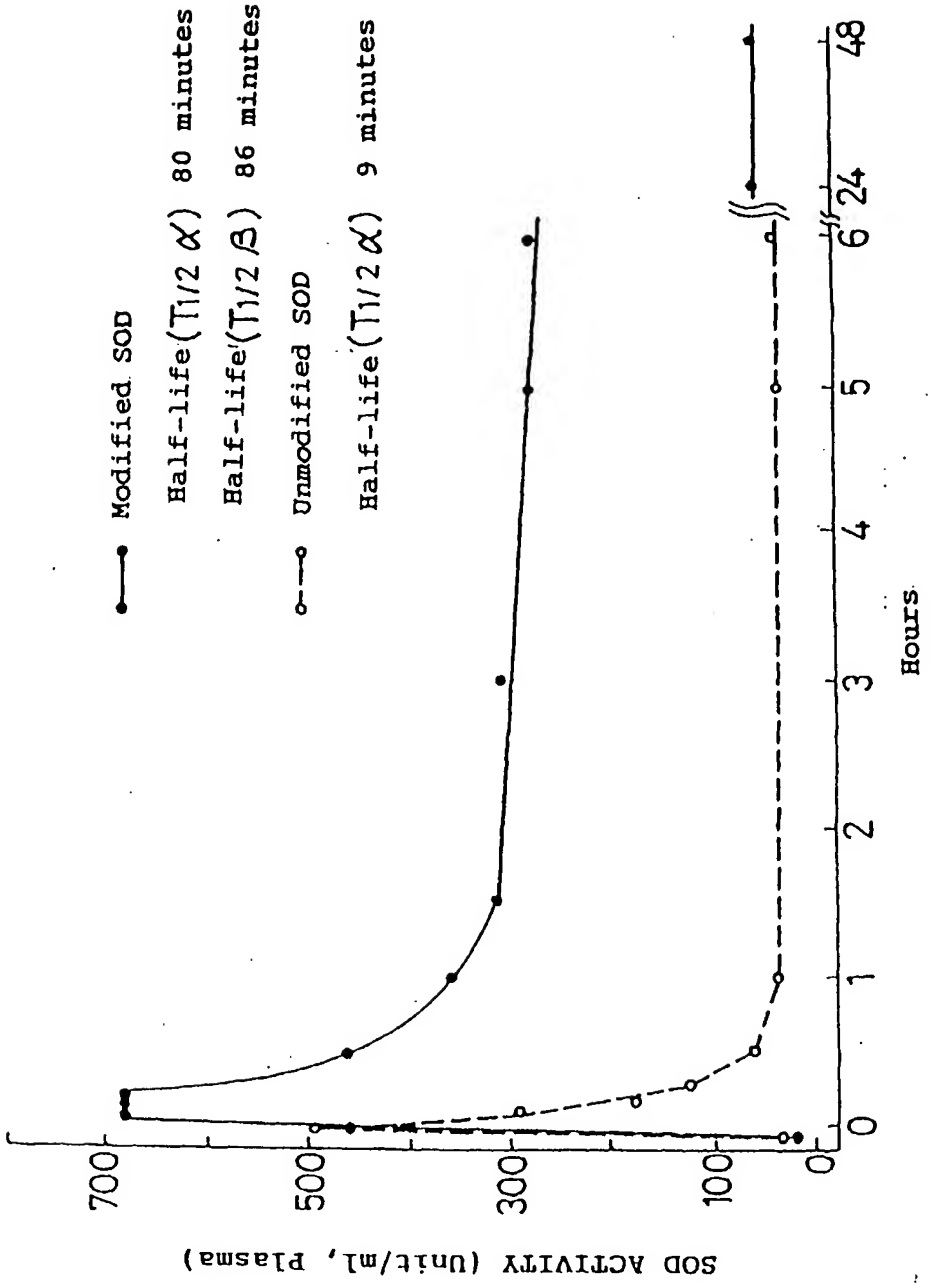
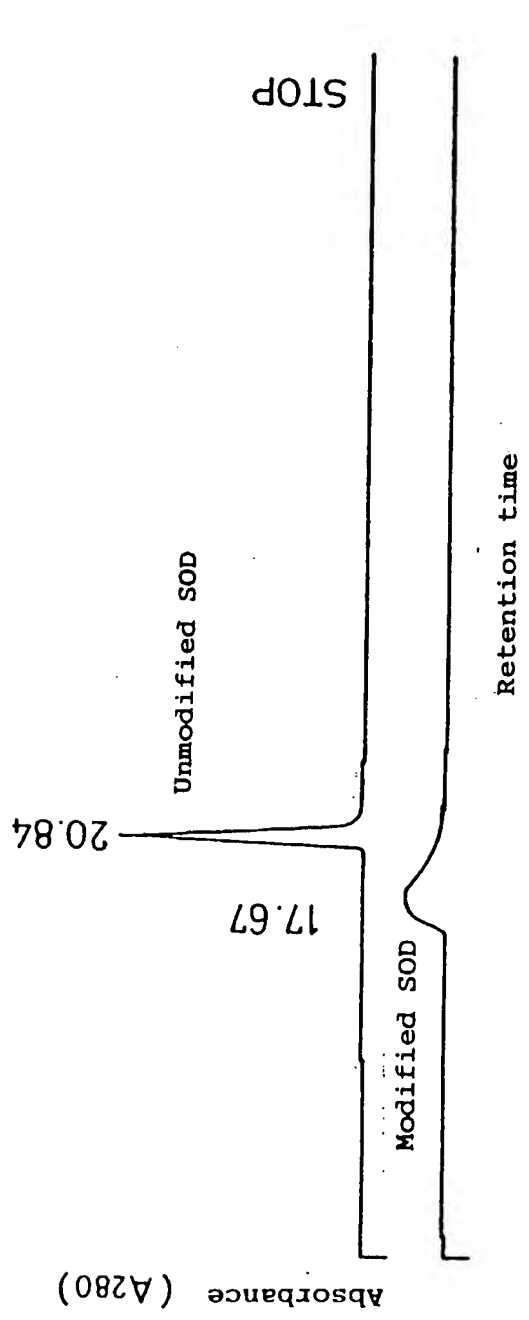

Modified SOD
Half-life ($T_{1/2}\alpha$) 80 minutes
Half-life ($T_{1/2}\beta$) 86 minutes
Unmodified SOD
Half-life ($T_{1/2}\alpha$) 9 minutes
SOD ACTIVITY (Unit/ml, plasma)
700
500
300
100
0
0
1
2
3
4
5
6
24
48
Hours

FIG. 2


STOP
Unmodified SOD
20.84
17.67
Modified SOD
Retention time
Absorbance (A280)